GEMS Simulations of the Impacts of Land Use and Climate Change on Carbon Dynamics in South-Central Senegal

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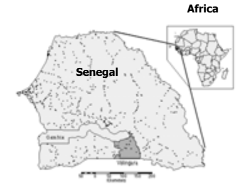
Introduction

The continuing rise of atmospheric CO_2 concentration will likely affect the stability of Earth's climate system, human health, and the sustainability of socio-economic systems. Carbon (C) dynamics in terrestrial ecosystems has been one of the major factors affecting CO_2 concentration in the atmosphere. Quantification of the spatial and temporal variability of C sources and sinks at the regional to global scales has been challenging because land-atmosphere C exchange is influenced by many factors, including land use and land cover change, CO_2 fertilization, nitrogen fertilization, and climate variability and change. Nevertheless, to slow the rising rate of atmospheric CO_2 concentration, developing countries can sell C sequestration credits to developed countries for offsetting C emissions under the United Nations Framework Convention on Climate Change.

In this study, we first describe and illustrate how a model may be built to simulate carbon dynamics in space and time with a special emphasis on the fusion of land use change data into model simulations. Then, the model is applied to estimate the spatial and temporal changes of C stocks in south-central Senegal from 1900 to 2100. Finally, management options are discussed from the perspective of carbon sequestration potential and regional sustainable development.

Study Area

The Department of Velingara is located in the south-central part of Senegal, covering an area of 543,414 hectares. The mean annual precipitation from 1961 to 1996 was 843 mm with a distinct rainy (June to October) and dry season. The mean monthly temperature is 28.1 °C, fluctuating between 24.4 °C and 32.1 °C.



Senegal showing the location of the study area of the department of Velingara (dark gray). The dots represent long-term field sites used to monitor biophysical changes.

Typical Sudanian zone landscape in the Department of Velingara.

Methods

Modeling Design

Equilibrium Carbon Status (Spinning-up run – 1500 years)	Historical Human Disturbances (100 years)	Land Use and Climate Change (100 years)

Time — 1900 — 2000

Estimates of the spatial patterns of carbon stock and fluxes in Velingara in 1900 were obtained by setting up the GEMS to run for 1500 years under potential vegetation, climate information from 1961 to 1996 (repetitively used), soil, and drainage conditions.
Carbon stocks in vegetation and soils were measured in undisturbed forests and used for model validation.

Starting from the estimated carbon status in 1900, GEMS simulated the impacts of human activities on carbon dynamics by incorporating land cover and land use change information.
Carbon stocks in vegetation and soils measured the field, historical grain production and agricultural area in Velingara were used to verify model simulations.
Land use information (e.g., crop composition, crop rotation probability, grazing, fire, fertilization and irrigation) from literature and census were incorporated in model simulations.

Climate change scenarios from 2000 to 2100 were based on the simulated results of seven global climate models (GCMs) (Hulme et al. 2001). Three scenarios were considered in this study: No Climate Change Scenario (NCCS), Low (LCCS) and High (HCCS) Climate Change Scenario. We also investigate the impacts of two wood harvesting scenarios (business-as-usual scenario, and no commercial wood harvest). The impact of fallow on C dynamics is investigated using two scenarios: business-as-usual and agricultural intensification scenario.

GEMS

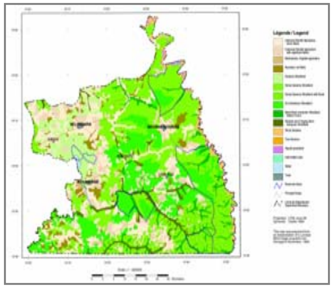
Carbon dynamics in vegetation and soils is simulated at the spatial scale of 80 m using the general ensemble biogeochemical modeling system (GEMS) developed at the USGS EROS Data Center. GEMS is a modeling system that was developed for a better integration of well-established ecosystem biogeochemical models with various spatial databases for the simulations of the biogeochemical cycles over large areas. GEMS consists of three major components: one or multiple encapsulated ecosystem biogeochemical models, a data assimilation system (DAS), and an input/output processor (IOP). GEMS deploys the encapsulated model on the basis of a joint frequency distribution of major variables.

Land Cover Change

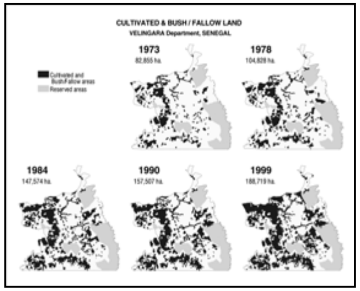
Land cover change information was mapped from from Landsat images acquired in 1973, 1978, 1984, 1990 and 1999, and field checked in 1984, 1996 and 2001.
Woodlands, including dense savanna woodland and dry deciduous woodland, are still the dominant land cover in the Department (Table 4). However, the woodland (all the land except agricultural land, water bodies, and towns) share decreased from 85% in 1973 to 63% in 1999. Meanwhile, the agricultural land fraction increased from 15% in 1973 to 34% in 1999. Dense savanna woodland area reduced steadily primarily caused by forest clearing and degradation.

Temporal changes of the percentage of major land cover classes from 1973 to 1999.

	Year				
Land Cover Class	1973	1978	1984	1990	1999
Dense Savanna Woodland	30	29	26	25	21
Dry Deciduous Woodland	23	21	18	17	16
Dense Savanna Woodland With Bowe	15	14	14	14	14
Extensive Ag Land With Some Fallow (1-3 years)	9	11	8	9	13
Bushland, Old Fields	0	0	5	3	13
Intensive Ag Land With Few Fallow (0-1 year)	6	8	14	17	8
Savanna Woodland	8	8	6	6	5
Moist semi-Evergreen Woodland, Gallery Forest	4	4	3	3	3
Riparian Forest	3	3	3	3	2
Shrub Savanna	2	2	2	2	2

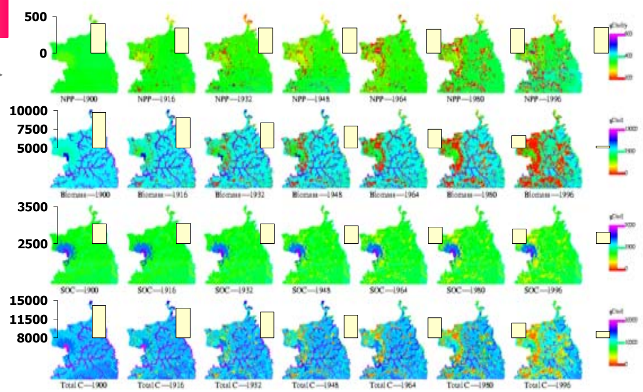


Land use / land cover classification of the Department of Velingara based on interpretation of a 1990 Landsat image and extensive field work.



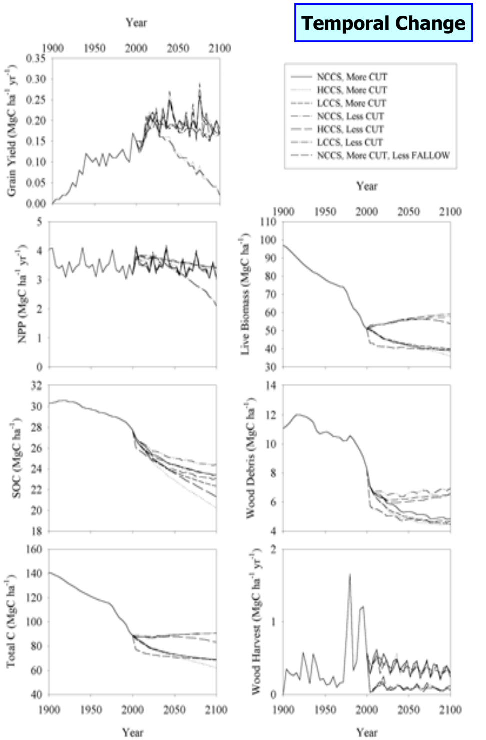
The expansion of agriculture in the Department of Velingara from 1973 to 1999.

Spatial Patterns



Model simulated changes of spatial patterns of net primary productivity (NPP), C stock in live biomass, soil organic carbon (SOC) in the top 20 cm layer, and total C stock in the Department of Velingara from 1900 to 1996.

Temporal Change



Carbon dynamics from 1900 to 2100 in Velingara under various management and climate change scenarios. NCCS: No Climate Change Scenario; LCCS: Low Climate Change Scenario; HCCS: High Climate Change Scenario; CUT: commercial harvesting of fuelwood

Summary

- **Simulated historical grain yield, land in agriculture, net primary productivity, soil organic carbon content, forest standing biomass, woody debris, and the accumulation rate of carbon in fallows were all in agreement with field measurements and census statistics.**
- **Total carbon stock in vegetation and soils went from 141 MgC ha^{-1} in 1900 to 89 MgC ha^{-1} in 2000, a reduction of 37%.**
- **The decrease of total carbon stock in this region will continue during the 21st century unless forest clearing is stopped, selective logging for fuelwood is dramatically reduced, and climate change, if any, is relatively small.**
- **Without further expansion of agricultural land, the development of a sustainable fuelwood and charcoal production system from the existing forests could be the most feasible and significant carbon sequestration project in the region.**
- **If future climate changes dramatically, as some of the global climate models have predicted, the productivity of the existing croplands will drop more than 2/3 around 2100, posing a serious threat to food security and the efficiency of carbon sequestration projects.**

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